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PLANE COORDINATES FOR INDUSTRIAL SITES

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SURVEYING AND MAPPING DIVISION

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PLANE COORDINATES FOR INDUSTRIAL SITES

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SYNOPSIS

Industrial developments are specially engineered to meet peculiar functional requirements at particular sites. This results in very dissimilar site developments but all are characterized by relatively large tracts of from 25 to 2500 acres, large total investments in the range of from $500,000 to $500,000,000 and great concentrations of plant which may run as high as $5,000,000 per acre in the principal center of the tract. Economic considerations make it generally infeasible to move to a new site so that an initial period of growth is followed by a period of additions, removals and rearrangements to maintain a competitive position over a long period, usually not less than 50 years.

High quality controlled surveying and mapping are required to insure fit between office plans and field construction and to insure the coordination and protection of aerial and underground plant during the course of construction, maintenance and operation throughout the long life of an expensive project. Net overall savings will result from the use of State Plane Coordinate control for all work and the total cost of this control is likely to be less than the cost of a single blunder which might result from inadequate or poor control.

General economic and technical requirements for controlled surveying and mapping at industrial sites are discussed and followed by a description of the application of State Plane Coordinate control to one of the radio stations used for public overseas telephone service.

General Requirements for Control

Some form of control is required to insure an acceptable degree of mutual consistency between boundary surveys, planimetric and topographic mapping, office plans, construction staking and location records affecting the maintenance and protection of plant. The essential requirement for controlled surveying and mapping is to provide accurate means for the translation of positions and elevations between the site and the office so that work can be planned to fit the site and so that office plans can be carried out in the field with a minimum of field changes and associated delays or extra costs.

If the control is inadequate or poor there will be a lack of fit between plans prepared in different offices and between the several plans and actual physical conditions at the site of work. Expedient or hasty changes in plans or deviations in field construction will be frequent and sometimes costly or unsatisfactory. Work will be duplicated from time to time, errors may accumulate to large values and a history of trouble on previous work at the site may lead to high bids and the waste of much time in unsystematic checking and adjustment work.

No great experience with industrial sites involving either large tracts or

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many items of plant is required to learn that starting with some initial survey or building line and constructing and dimensioning successively from one plant item to the next leads to large cumulative errors. These may not be discovered until a measurement is made from some other point or when boundary trouble or damage to underground installations results.

The protection of underground plant is a problem of increasing importance owing to more common use of underground utilities and process interconnections and increasingly greater dependence on the continuity of these utilities. Concomitantly the risks to underground plant are increasing with more common use of large excavating and earth moving machines which have increased the feasibility of making deeper cuts and moving greater quantities of earth. Erosion or grading operations may change the covering of underground plant and expose it to greater risk of disturbance, particularly if records are left in terms of depth below the original surface. The referencing of plant in the vertical plane in terms of elevations above the standard mean sea level datum is desirable. Damage to underground utilities usually results in serious interruptions of the utilities or plant process and may involve safety or fire hazards. Blunders of this character may be very expensive and their frequency of occurrence makes it seem prudent to explain the need for good control in advance rather than to incur the risk of having to explain why it was not provided.

All surveys are susceptible to errors and blunders and general knowledge of this fact leads to the closing of surveys on some coordinate system and commonly to the use of many unrelated and arbitrary coordinate systems throughout the life of a site. This is uneconomical and a nuisance at best and sometimes leads to temporary time-wasting confusion or to the perpetuation and compounding of blunders. Accordingly, a single plane coordinate system is desirable for use at a site and is common practice for sites under good management. The use of a single azimuthal equidistant local coordinate system is, of course, preferable to no control but has the disadvantages of lack of fit with other surveys in the area, a lack of official status and a limitation to small areas by reason of defects in the projection. An isolated local coordinate system usually proves to be an expedient but bad choice since it tends to remain in use long after its limitations are exceeded. Translations to a better system although basically simple tend to be deferred, it is difficult to locate and correct all records in terms of old coordinates and the translation work is usually complicated by the existence of unadjusted work.

The State Plane Coordinate Systems

The State Plane Coordinate Systems established for each State and Territory of the United States provide means for effecting a mutual consistency between all surveys in the State while requiring only ordinary plane surveying methods for the separate small area surveys. Plane coordinates are assigned to great numbers of control monuments scattered throughout each State and in accord with a sound mathematical projection system which takes proper account of the true shape of the earth which is neither flat nor round. The basic projection and control work is carried out by the U. S. Coast & Geodetic Survey, State geodetic control agencies and by surveying specialists. No knowledge of the projection is required for the use of the systems by ordinary surveyors provided the work is started and closed on control monuments with all values in terms of State Plane Grid azimuths, grid distances and plane coordinates and with the results being adjusted for exact fit with the fixed control net.

Economic Considerations

Expansion of the State Plane Coordinate net to provide local control affects overall economies and firm control for the long-time development of an industrial site. Initial costs for the expansion and local control are determined by the nearness of existing control monuments and the density of control points required for the most economical development of the site. As rough indices, the total costs for the expansion and local control are likely to run from about $1,000 or 0.5% of total investment for small sites to $10,000 or 0.1% of total investment for large sites with a need for a substantial local net. In some instances where existing control monuments are found on or near the site the cost for expansion from the existing control monuments will be trivial. Ordinary surveying equipment and methods can be used for most control work of this nature. The advice of a geodetic engineer and the use of modern optical theodolites reading to one second or better will be profitable for large or expensive projects or for work requiring large expansion figures.

The existence of a control net affects economies in locating and planning work, insures fit and avoids the duplication of work throughout the life of the site. With good planning all subsidiary surveys are adjusted for exact fit with the previously fixed net and serve as area expansion surveys affording an increasing density of control with plant growth. In many instances all the principal points of new construction can be located by triangulation intersections with substantial savings in cost over ordinary traverse work.

The establishment of adequate control nets at radio stations has resulted in reductions in costs for construction staking surveys in the range of from 40 to 60%. For one new station the cost of the control work was recaptured in the initial development stage. On the basis of this experience it seems likely that the use of firm control under the State Plane Coordinate Systems will equate to the least cost on a present worth basis at most industrial sites. In any event, the costs will be very small in relation to the total investment in plant and will be recaptured if a single blunder is avoided. Everything fits and there is greater confidence and less lost time in the office and in the field.

Control for the Fort Lauderdale Radio Station

General Nature and Function of the Station

Four control offices and ten radio stations are operated by the American Telephone and Telegraph Company for the furnishing of public overseas telephone service connecting with nearly all of the worlds telephones. Most of this service is furnished on multichannel high-frequency radio circuits operating with speech scrambling devices to insure the privacy of conversations and with directive beam antennas for transmitting and receiving. Some form of azimuth control is required for the aiming of directive antennas but this requirement is not severe from a surveying standpoint because some beam width is required to account for wandering of the radio signals from the great circle path, especially at times of ionospheric disturbances. The greatest need for survey and map control arises as a result of the need for fitting large numbers of antennas and other plant items both aerial and underground on a relatively large tract but with heavy concentrations of plant near the central equipment buildings. Three-dimensional control is required over the station tracts which vary in size from about 200 to 2800 acres.

Fort Lauderdale is one of the smaller stations and serves as a radio receiving station combined with a control office where the transmitting and

receiving branches of the lines from toll switchboards in Miami are subjected to volume regulation, speech scrambling, noise reduction, echo and singing suppression and where the technical operation of the receiving and transmitting facilities at the United States and the distant ends of the overseas circuits are coordinated by a staff of technical operators.

Historical Development of the Control Nets

The Fort Lauderdale station was placed in service in 1948 and was the first of the radio stations to have an adequate control net established in advance of any construction work. All plant was located by triangulation intersections and all surveying, mapping and planning is under control from the net. The State Plane Coordinate System for the Florida East Zone is used exclusively for all field work, office plans and as the reference to position in correspondence between offices. Reference marks in the floor of equipment spaces are used for the location of equipment and are tied to the State Coordinate net. Vertical control is on the standard Mean Sea Level Datum of 1929.

Although a net of some character exists at each of the older shortwave radio stations, these have evolved from single astronomic observation lines or from simple isolated figures. Expediency operated to retain weak elements in these early nets but improvements were made from time to time when difficulties developed or locating costs became excessive. These older nets are being strengthened and placed under State Plane Coordinate control as this proves necessary or feasible. It is this systematic readjustment work which produces the best evidence of the economy of establishing firm control on the State coordinate grid before any construction work is started. Although the old surveys were made with 20-second instruments and with more than ordinary care, they were undertaken for specific immediate uses, failed to yield strong integrated nets and distortions and cumulative errors resulted from independent adjustments of small figures. The most common fault is wandering in azimuth as the combined effect of small figures, independent adjustments, instrument precision and convergence of the meridians without the control of a systematic projection grid. The final results usually disclose hidden risks to underground plant resulting from cumulative errors. Other common errors are found to have resulted from dimensioning from objects which have been moved physically or on paper in reissues of plans. One instance was discovered in which old correspondence indicated that appreciable time was spent in an unsuccessful attempt to reconcile an apparent error in field work. No significant error was found when the work was computed on the State Grid and the previous difficulty was found to result from a somewhat obscure involvement with the shape of the earth.

Reconnaissance and Preliminary Mapping and Planning

In the site screening phase radio field strength and noise level measurements were made at a number of locations in the general area from Miami to Fort Lauderdale. One of these test locations was within a few hundred feet of the site finally selected. Only the boundary survey was completed prior to the control work. This survey was tied to the control net in both the reconnaissance and final stages and was found to be very accurate. This is not the usual situation since substantial errors have been found in most of the boundary surveys which have been tied to control nets at some later date. Flood level studies, subsoil investigations and soil corrosion tests were carried out as part of the general reconnaissance work.

information on all existing control in the vicinity was obtained from the U. S. Coast & Geodetic Survey and other agencies as soon as the site was selected and reconnaissance was started in advance of construction. The reconnaissance observations together with the boundary survey were used to derive a preliminary solution of the control net and to prepare preliminary plans for the construction. A 20-second transit was used for this work but a 1-second theodolite is more suitable since speed with accuracy is desirable, especially in this phase where it is necessary to keep ahead of planning and construction requirements. A Wild T2 has been used for more recent work.

Two hurricanes experienced during the reconnaissance resulted in the general flooding of the area and all of the reconnaissance, and most of the final control and construction staking surveys were made in rubber boots with flooded settings. This produced results which were acceptable but somewhat less accurate than results obtained with the same modified 3rd order specification under better conditions. The stripping of obstructing palm fronds and pine branches by the two hurricanes cleared lines which would have been obstructed normally and lent substance to the old proverb "It's an ill wind that blows no good."

The Principal Expansion Figure

Since no control other than the USC & GS net was available in this vicinity, expansion to the site was made by 3rd order triangulation as shown in Figure 1. The USC & GS station HAWKINS is a first order station and while it would have been feasible to obtain control by an 8000-foot traverse from this station, triangulation was preferred to insure the recovery of undisturbed initial stations and verified position and azimuth. Experience at other radio stations has indicated that it is good practice to effect agreement with a minimum of three initial monuments.

An expansion yielding a distance check is desirable but this was not feasible in this instance since it would have required high towers to clear adjacent pine ridges. Distances in the local net were obtained from a local base measured forward and back with a 100-foot steel tape provided with a tension handle and two tape thermometers all calibrated by the National Bureau of Standards. Good procedure with scribing strips on firm stakes, heavy tension, overcast sky, no wind, no moisture or oil on the tape, corrections for slope, temperature, pull, and reduction to sea level were employed and yielded a difference of 0.001 foot between the two measures of the 1290 foot base. This equates to a probable error of 1 part in 3,800,000, and is about the same order of accuracy obtained with the same specification on other radio station base lines.

The principal local net station AMTEL 1 together with the USC & GS stations HAWKINS, BROWARD BOULEVARD MUNICIPAL WATER TANK and FLORIDA POWER & LIGHT CO. WATER TANK provided an expansion quadrilateral. Elevated water tanks and towers are usually intersected by the U. S. Coast And Geodetic Survey and other control survey organizations and provide reasonably permanent and fairly stable high marks affording visibility over great areas. They are extremely useful to engineers and land surveyors engaged in expansions for local control and serve as handy azimuth marks for subsequent work from the control net. Their usefulness in arriving at the final goal of control for all survey and mapping work warrants consideration of higher orders of accuracy for the original supplemental intersection work by the principal control agencies, well centered finials or lights suitable for night work and means for occupation with an instrument where the structure is adaptable to this purpose.

In this case, the Florida Power & Light Co. Water Tank had a rigid catwalk extending to the feed pipe immediately under the tank and this was occupied as an eccentric station to strengthen the expansion figure. Three sets of measurements each comprising 6 repetitions of the angle with the telescope direct and six repetitions of the explement with the telescope reversed for each angle and the horizon closure were made with a 20-second transit. This instrument has been used successfully on several control surveys and is maintained in good mechanical condition and near perfect adjustment. The instrument was modified to obtain improved circle and vernier centerings and a superior telescope. An optical reading one-second theodolite has been used on more recent work and affects net economies in time and money. The probable error for the important line from the first-order station HAWKINS to the principal local station AMTEL 1 was one in 40,000 as derived from the strength of figure and the probable error of the angle measurements. The principal expansion was computed geodetically. This is preferable if the engineer is familiar with the work but computations on the State Plane Coordinate grid are entirely satisfactory if the simple instructions for correction terms for long lines are followed.

The Local Control Net

The local control net consists of two quadrilaterals with a short traverse spur to the west quarter-section corner as shown in Figure 2. This is a site with a good boundary survey, flat open terrain subject to occasional flooding, and ordinary good atmospheric visibility. Accordingly, the requirements for this particular station were to effect a firm tie to the boundary, to locate stations on the roads or embankments which are the only points with appreciable height affording good visibility and to provide a simple net of relatively large figures disposed to leave lines yielding strong figures for the location of any point on the tract by intersection triangulation from the control monuments. Substantial savings in cost and improved accuracy in location surveys are effected by substituting triangulation for wiggly expensive traverse.

One set of measurements each consisting of 6 repetitions of the angle with the telescope direct and 6 repetitions of the explement with the telescope reversed for each angle and for the horizon closure were made with a 20-second transit on a tripod set on wooden plugs driven firmly in the sand at 120-degree points on a circle of 2.5 foot radius from the station monument. The results were adjusted in general accord with the method of least squares but with separate adjustments for angle conditions and for side conditions by the rigid method. This is entirely satisfactory and was done to provide an example of the method for use as a guide on other work where an engineer with geodetic experience would not be available. Independent geodetic and plane coordinate computations were made for the local net.

The computations of geographic position are a mere convenience peculiar to radio stations involving directive antennas and are not necessary for industrial sites in general. The geodetic data are used only in the office and all field work and correspondence are in terms of the State Plane Coordinates.

The probable error for the weakest line in the local net is 1 part in 67,000 and the probable error for an azimuth is 2.18 seconds. No requirement for higher accuracy is likely to arise during the life of the station. This is the proper test of the adequacy of a control net and expedient solutions which fail to meet this criterion will not be most economical in the long run.

It is noted that the location of local control monuments, the configuration of the net and the length of lines need to be determined according to the

peculiarities of the local terrain and visibility conditions and with knowledge of probable developments and needs at the particular site. The control nets for the several radio stations show great dissimilarities and only basic considerations are applicable to industrial sites in general. Relatively large figures are appropriate for the location of large antennas and the size of figures is controlled by terrain and atmospheric visibility conditions. At Ojus, Florida there is a heavy growth of palmetto which prompted the use of one survey station on a building roof with 3 other stations in a single large quadrilateral with semi-permanent instrument settings above the palmetto growth. At Point Reyes, California frequent invasions of dense marine fog make it necessary to use small figures. At Dixon, in the Sacramento Valley, severe atmospheric boiling and optical haze make it difficult to work from the ground and may obscure ranging rods at 1000 feet. Here one station elevated on the roof of a sturdy building and 8 stations forming a closed loop of 4 quadrilaterals about this central station are used to insure visibility. To improve visibility and to provide firm settings in ground crazed by dry-season shrinkage polygons, low semi-permanent instrument settings were provided. These also protect the monuments from heavy irrigation farming machinery and are designed to serve as air-photo identification marks.

Monuments

Five of the monuments in the Fort Lauderdale net were set by the boundary surveyor and are pipes in a concrete surface monument according to the Florida specification for Permanent Reference Monuments. One monument marking the center of the tract was buried in the construction of the entrance road and the surface monument for AMTEL 2 was constructed above and centered over the buried land survey monument. AMTEL 1 and AMTEL 3 have underground and surface monuments with 90 mm bronze disks according to the standard notes of the U. S. Coast And Geodetic Survey. The character of monuments needs to be adaptable to the special conditions at the monument site but flush or buried monuments with substantial projecting guards seem to provide best insurance against disturbance. No monument should be regarded as permanent and this is one of the best recommendations for use of State Plane coordinates.

The markers in the floor of the equipment building are special turning lathe details to insure concentricity of the center mark when it is adjusted to be level with the final floor covering. This is a one story building but on multiple story buildings control markers with exact register between floors are installed to provide for the location of conduit runs and other interfloor connections. Figure 3 which is a cartoon by artist George Price and reproduced with the permission of The New Yorker Magazine is a most concise and forceful argument for horizontal control.

Vertical Control

Vertical control was obtained by a loop of 3rd-order spirit leveling commencing with Bench Mark J99 and closing on BM H99, both being 2nd-order benchmarks of the U. S. Coast and Geodetic Survey located along the West Dixie Highway at the west boundary of the radio station. This vertical control was undertaken only after the horizontal control was completed and the results of this short delay emphasize the desirability of establishing control in advance of any planning or construction. Elevations on 6 different reference planes were found in use before the vertical control was run and all elevations

were adjusted to the standard Mean Sea Level Datum of 1929. Three sets of elevations, used for land, roads and buildings, respectively, and with appreciable inconsistencies had started from supposed record elevations for the crown of the West Dixie Highway. One of these started with a road elevation at a point 40 feet from USC&GS BM J99 and although a side shot was taken on this bench mark no attempt was made to obtain the record elevation for the bench mark. The other three sets of elevations were those of drainage control agencies the records of which are important for planning at a site subject to occasional flooding. An attempt has been made to mark all old correspondence and records to show the one or more corrections required to reduce elevations to the standard datum but there is a residual risk of some old elevation on an unidentified datum turning up to cause confusion.

Mapping

The base map for the station is a topographic map at the scale 1 inch = 100 feet (1:1200) with State Plane Coordinate grid lines at cardinal 500 foot values and a contour interval of 1 foot on the mean sea level datum. The mapped area is kept free of dimensioning or legends and complete geodetic and plane coordinate control data are shown in one marginal table and complete dimensional and plane coordinate data for the antennas are shown in another marginal table. Only these data and standard drawings of construction details would be required to effect a quick restoration of damage from debris flying in a severe hurricane. The antennas are designed to withstand the direct effects of hurricane winds.

The master tracing of this map carries no title, borders or legends and is used solely for the production of reversed contact positives on tracing cloth for completion as special purpose maps in the several offices involved in the operation of the overseas services. No significant detail is added to the base map which does not have a proved accuracy of 1 part in 5000 for distance and 5 seconds in azimuth. Additions are plotted only from the adjusted results of surveys for the construction as actually built. Contemplated or planned work is shown only on the special purpose maps prepared from the reproduction tracings.

All plant and the principal planimetric features shown on the map were located by triangulation intersections from the control monuments. Topographic features and minor planimetric features were plotted from stadia measurements supplemented by radial plotting and photogrammetry from near vertical aerial photos flown at 5000 feet with good overlap and printed at a uniform scale of approximately 1 inch = 330 feet. Oblique aerial photos are available in black and white and in color for interpretive and general planning work.

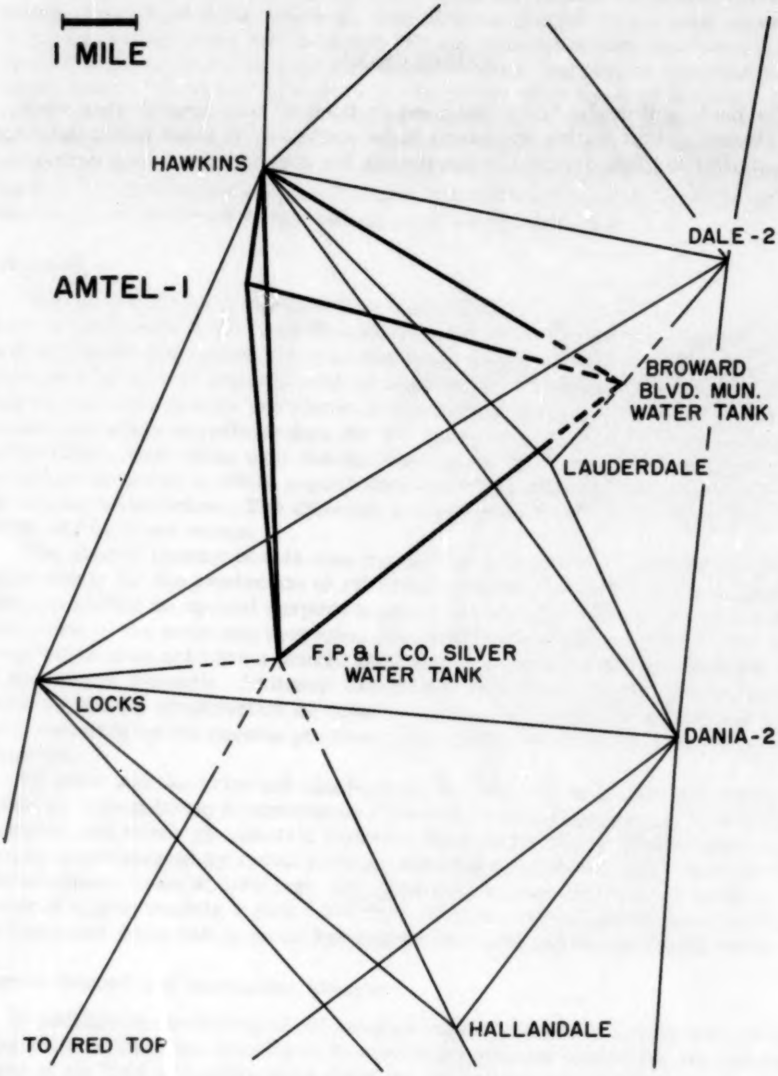
Survey Record and Instruction Manual

In addition to the listing of all strictly essential control information in tabular form on the base map there is a separate volume containing reproductions of all field and office work from the reconnaissance through the final computation and record sheets for each station. A copy of this volume is on file at the station and in each engineering office concerned with work at the station. Copies were furnished to the U. S. Coast And Geodetic Survey and the Broward County Engineer. The volume includes extracts of the plane coordinate projection tables, an explanatory mathematical development of the projection, a manual for the use of the State Plane Coordinate control system, some graphic and other computational shortcuts applicable to the specific

station and some general descriptive material useful to engineers engaged in work at the station.

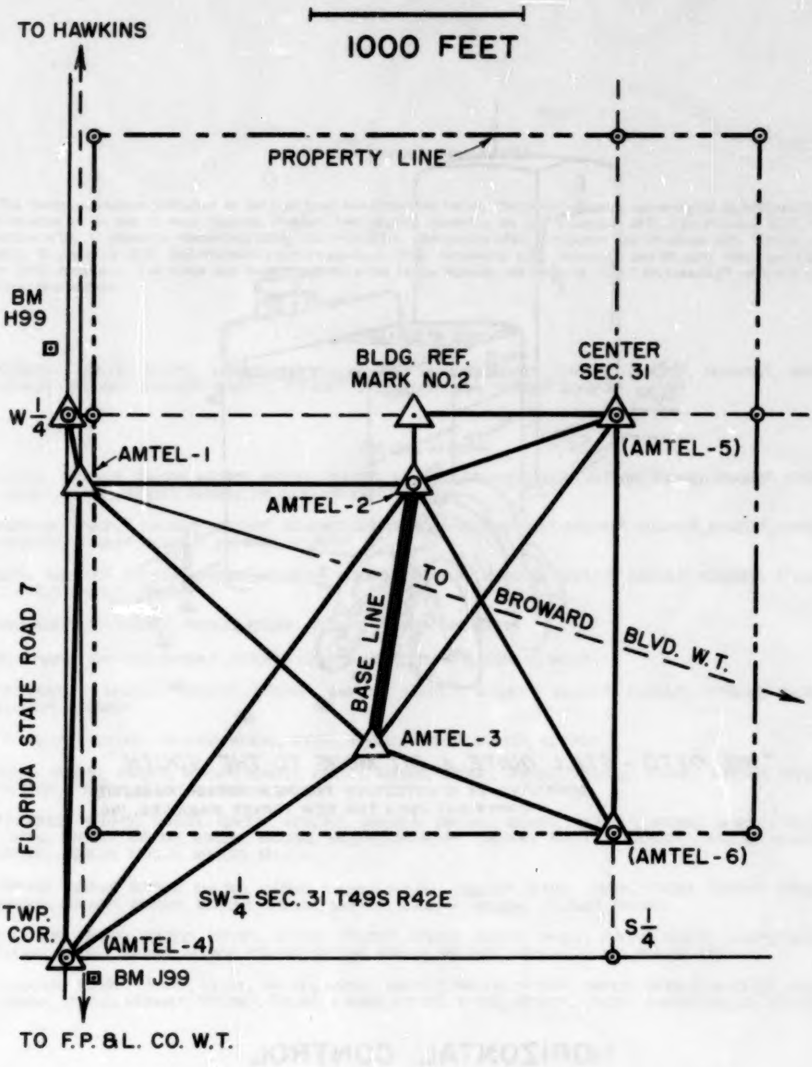
CONCLUSION

The basic philosophy "Do it once and do it right" was applied when work was started at this station and seems to be applicable to most industrial sites with similar but not identical requirements for control over a long period of time.

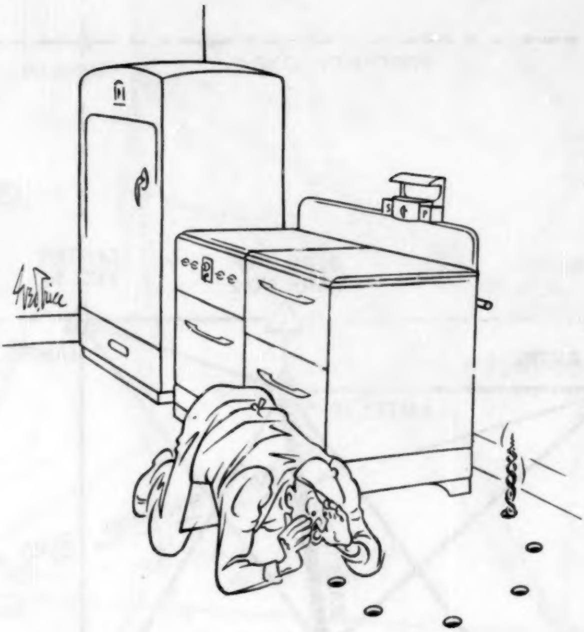


PRINCIPAL CONTROL TRIANGULATION

FIGURE 1



LOCAL CONTROL NET
FIGURE 2



"NO, OTTO – STILL QUITE A BIT MORE TO THE SOUTH."

HORIZONTAL CONTROL
FIGURE 3

PROCEEDINGS-SEPARATES

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c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.